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FOR

Method and Apparatus for Color Correction

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Method and Apparatus for Color Correction

FIELD OF THE INVENTION

5 The present invention relates to the field of digital image processing. In particular the present invention discloses a graphical user interface and methods for performing color correction and color keying.

BACKGROUND OF THE INVENTION

10 Recent advances in video processing technologies have led to a surge in popularity of new video processing applications that make powerful video editing capabilities available to a wide base of users. Typically, video processing applications allow users to download and upload video and audio segments, as well as edit and
15 manipulate these segments for producing a cohesive video or movie.

 In performing such tasks, video processing applications often use a video capture card to capture and store video segments onto the hard drive of a computer system. Video capture cards typically employ a coder/decoder (also called a "CODEC")
20 to compress the video with a compression standard such as Motion-JPEG, DV, MPEG-1, MPEG-2, etc. Many digital video storage formats store pixel data in a luminance and chrominance colorspace often referred to Y/Cr/Cb (also referred to as YUV). In a luminance and chrominance colorspace three components are stored for each pixel: one for luminance (Y) and two for color information (Cr and Cb). Most computer display
25 systems store pixel information in an RGB format that also contains three components

per pixel, one each for the Red (R), Green (G), and Blue (B) portions of the color. Pixel information stored in either YUV or RGB format can be converted to the other format using straightforward matrix mathematics.

5 In the DV (digital video) storage format, storage is typically accomplished with an 8-bit luminance (Y) value for each pixel. 8 bits allows luminance (Y) values ranging from 0 through 255. In 8-bit digital video, black is typically encoded at $Y = 16$ and white is encoded at $Y = 235$. The luminance values from 1 to 15, referred to as footroom, and 236 to 254, referred to as headroom, are used to accommodate ringing and
10 overshoot in a signal. Industry standard equations (such as those specified by Rec. ITU R BT-601) can convert 8-bit RGB encoded images with RGB values ranging from 0 to 255 into YUV encoded images with luminance (Y) values ranging from 16 to 235. Most software DV CODECs follow this mapping so that a user may translate, say, naturalistic computer pictures into quality video.

15 However, there are several phenomena which may contribute to degradation or compromising of the dynamic range of given colors in a resulting video segment. For example, difficulties often arise, for example, because cameras can often capture values that are superwhite (values resulting from specular reflections, sun, or
20 bright lights, clouds or white walls). Superwhite values may exceed the nominal white value of 235 as registered on a waveform monitor, where these whites may peak at 100 IRE (NTSC) which is the brightest value allowable on a broadcast RF modulator. In the YUV space, the Y values range from 235 to 254; but on a waveform monitor, whites can be seen to range from 100 IRE to almost 110 IRE, all of which represent illegal values
25 (e.g., Y values above 254), and are accordingly clipped to 254 by a CODEC when

converting to RGB, thereby compromising the dynamic range of at least the white value in a given digital image.

Typically, users may attempt to mitigate such value degradation by
5 employing color correction of the RGB space. A problem arises, however, because color correction, still yield only a limited amount of headroom for colors (such as superwhite), and also require extensive operations cycles, execution time, and memory access in computer systems that support digital video processing applications. Inherent in such a problem is the need for rendering, where editing is translated and stored on the hard drive
10 a computer system supporting a given video image processing application. Even recently developed "real time" systems still need to go back to rendering in cases where a user simultaneously color corrects, adds filters, effects, and superimposes graphics, even for a high end real time system, the capacity will be overwhelmed and the real time performance will be compromised. As such, there are still deficiencies not addressed by
15 recent advances in video processing, which in particular concerns the limited overhead on color values and a less expensive approach to color correction.

SUMMARY OF THE INVENTION

A graphical user interface for performing color correction and methods for implementing the color correction are disclosed. The graphical user interface allows a user to adjust the colorspace of the pixels in the image. In one embodiment, a color adjustment pad allows the user to push the pixels from a particular luminance level a desired magnitude towards a desired hue. Pixels from other luminance levels are affected proportionally. The graphical user interface further allows a user to adjust the luminance of the pixels in the image. A luminance adjustment slider allows the user to adjust the luminance of pixels from a selected luminance level by a relative amount. Pixels from other luminance levels have their luminance are affected in a manner proportional to a difference between the selected luminance level value and the luminance value of the other pixel.

Other objects, features, and advantages of present invention will be apparent from the company drawings and from the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects, features, and advantages of the present invention will be apparent to one skilled in the art, in view of the following detailed description in which:

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Figure 1(a) illustrates a conceptual diagram of a three-dimensional colorspace defined in the luminance (Y) and chrominance (UV) format known as a YUV format.

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Figure 1(b) illustrates a conceptual diagram of a three-dimensional colorspace of **Figure 1(a)** defined in an alternate hue (H), saturation (S), and luminance (Y) format.

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Figure 2 illustrates one embodiment of a graphical user interface for a color correction control system of the present invention.

Figure 3(a) illustrates a compliant video frame in the canvas window.

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Figure 3(b) illustrates a subsequent video frame in the canvas window with all the pixels close to an allowable maximum highlighted with zebra striping.

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Figure 3(c) illustrates a subsequent video frame in the canvas window with all the pixels close to an allowable maximum highlighted with a first zebra striping and all the pixels exceeding the allowable maximum highlighted with a second zebra striping.

Figure 4 illustrates one embodiment of a graphical user interface for the color correction window **230** of the color correction control system in **Figure 2**.

Figure 5 illustrates a white luminance plane, a mids luminance plane, and a blacks luminance plane in the colorspace of **Figures 1(a)** and **1(b)**.

Figures 6(a) illustrates the effect of moving the white luminance plane of the cylindrical colorspace representation to the right.

Figures 6(b) illustrates the effect of moving the black luminance plane of the cylindrical colorspace representation to the right.

Figure 7 illustrates the effect of moving the mids luminance plane on the cylindrical colorspace representation to the right.

Figure 8 illustrates the effect of moving the mids luminance plane to the right on a cylindrical colorspace already modified as illustrated in **Figure 6(a)**.

Figure 9 illustrates a first alternate embodiment of a graphical user interface for the color correction window **230** of the color correction control system in **Figure 2**.

Figure 10 illustrates a second alternate embodiment of a graphical user interface for the color correction window **230** of the color correction control system in **Figure 2**.

Figure 11 illustrates a flow diagram of one color correction implementation that performs color correction using look-up tables recomputed based upon user input from a graphical user interface.

Figure 12 illustrates a flow diagram describing pixel remapping using the color correction system of the present invention.

Figure 13 illustrates a graphical representation of an exemplary range of potential transitions for the different pixel luminance input versus pixel luminance output relationships within a lookup table for luminance correction.

Figures 14(a) to 14(g) illustrates graphical representations of the various input versus output relationships within a lookup table for luminance correction within the inventive system, as well as the control points of the Bezier curve which describes the M control modifications within the look-up table.

Figure 15 illustrates an unmodified cylindrical colorspace representation where the white (W), mid (M), and black (B) luminance planes are all physically centered on the $C_b = 0, C_r = 0$ axis, and where none of the values $U_W, V_W, U_M, V_M, U_b, V_b$ have been modified.

Figure 16 illustrates a cylindrical colorspace representation where the white (W), mid (M), and black (B) luminance planes have been pushed an equal amount to reflect changed Cb and Cr values regardless of luminance.

5 **Figure 17** illustrates a cylindrical colorspace representation where the white (W), mid (M), and black (B) luminance planes have been pushed such that Cb has been pushed negative at *M*, but *B* and *W* remain the same.

10 **Figure 18** illustrates the abstract control points that form the basis for an exemplary Bezier curve function called “gMidRamp”.

Figure 19 illustrates the gMidRamp function that can be used to calculate a look up table for Cb and Cr across the various luminance levels.

15 **Figure 20** illustrates the look up table that provides a Cb offset amount for a given luminance input, as a result of the application of the gMidRamp function to the modified colorspace of **Figure 17**.

20 **Figure 21** illustrates another example of a modified cylindrical colorspace representation where Cb and Cr have been pushed at *M* and *W*, but *B* remains the same.

Figure 22 illustrates the look up table that provides an offset amount for a given luminance input, as a result of the application of the gMidRamp function to the Cb example taken from the specific example in **Fig. 21**.

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Figure 23 illustrates the look up table that provides an offset amount for a given luminance input, as a result of the application of the gMidRamp function to the Cr example taken from the specific example in **Fig. 21**.

5 **Figure 24** is a flow diagram illustrating a broad description of the color correction according to the recomputation of YUV values by usage of look up tables in the inventive technique for keyed pixels.

10 **Figure 25** is a flow diagram illustrating an overall description of the pixel remapping of the inventive color correction over keyed pixels.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

A method and user interface for performing color correction is disclosed.

In the following description, for purposes of explanation, specific nomenclature is set forth to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that these specific details are not required in order to practice the present invention. For example, the present invention has been described with reference to Bezier curves. However, the same techniques can easily be applied with other types of curved functions.

Digital Video and Colorspaces

Digital video pixel information is commonly stored in a three component luminance and chrominance format. For example, both the MPEG-1 and MPEG-2 digital video standards encode pixel data with three component luminance and chrominance format.

The luminance specifies the brightness of a pixel. Luminance ranges from pure black to pure white. Luminance is typically expressed in a single component Y value. The chrominance specifies the color of a pixel and is stored as two component values Cr and Cb (that are also referred to as U and V values). One reason that digital video is stored in a luminance and chrominance format is that human vision is much more sensitive to luminance information than chrominance information such that separate chrominance information can be more heavily compressed without significantly detectable image degradation.

Computer display systems generally represent pixel information in a three component RGB format wherein the three components specify the amount of Red (R), Green (G), and Blue (B) required to represent a pixel. Pixel information stored in either RGB format or YUV format can easily be converted to the other format using simple matrix math.

Figure 1(a) illustrates a conceptual diagram of a three-dimensional colorspace defined in the luminance (Y) and chrominance (UV) YUV format. The two part UV chrominance value is not intuitive to humans. Thus, the colorspace often defined in an alternative hue (H), saturation (S), and luminance (Y) format.

Figure 1(b) illustrates an alternate interpretation of the three-dimensional colorspace in **Figure 1(a)**. The colorspace of **Figure 1(b)** is defined in terms of luminance (Y), hue (H), and saturation (S).

The luminance (Y) value continues to represent the brightness of a pixel. Luminance (Y) is represented as a vertical coordinate along the vertical axis of the cylinder of the cylindrical colorspace of **Figure 1(b)**.

The hue (H) represents a particular color value. Hue is represented as an angle from the center of the cylinder of the cylindrical colorspace of **Figure 1(b)**. Hue is often specified on a common color wheel.

Saturation (S) refers to the depth or intensity of a pixel's color (hue). In other words, how strong the color is relative to an unsaturated white/gray/black of the same luminance level. For example, a deep red has a high level of saturation (mostly pure red with little white) and a pinkish red is only lightly saturated (less pure red and a higher level of white). Saturation is represented in the colorspace of **Figure 1(b)** as a distance along a vector defined by the hue (H) angle.

Color Correction

Film and television feature productions generally go through three phases: pre-production, production, and post-production. The pre-production phase is when the script is created, the actors are cast, and the sets are built. During production phase, the actual film is shot or the videotape is recorded using the actors and sets. Finally, during the post-production, the film or video tapes is edited together, the sound is edited, music is added, special effects are added, and the film or video tape images are adjusted.

As part of the post-production process, the images from many films and television shows go through a process of "color correction." The process of color correction is used to fix color problems that occur during the filming or videotape production.

Professional colorists refer to primary, secondary, and tertiary color correction. Primary color correction involves fixing the basic color balance of an image to make it look correct with true color representation. Primary color correction problems include incorrect color casting from bad lighting, color problems caused by color filters,

and improper exposure. Secondary color correction problems are caused by mismatched colors for related scenes shot at different times or with different lighting.

Tertiary color correction is actually color enhancement such as making a scene darker to enhance a particular mood. Tertiary color correction is also used to perform certain special effects. For example, the director or editor may wish to change the color of specific objects in a scene. For example, the director or editor may change the color of clothing worn by a particular character. The director may change the eye color of characters such as the distinctive blue eyes in the feature film "Dune."

A Color Correction System

The present invention introduces a new color correction system that allows post-production specialists to have a wide latitude of control over the colors in series of images. The color correction system uses a highly intuitive graphical user interface such that post-production specialists can quickly learn the color correction system and professionally apply its features.

Figure 2 illustrates one embodiment of a graphical user interface for a color correction control system of the present invention. In the graphical user interface of **Figure 2**, there are three different windows for presenting information.

Image Canvas Window

A first window **210** is a "canvas" window that displays the video or other images that are being adjusted with the color correction system. In a preferred

embodiment, the canvas window **210** includes novel feedback systems that provide more information than just the image.

Images may contain pixels that exceed a maximum luminance value
5 allowed for broadcast material. Thus, it would be desirable to be able to identify and locate pixels that exceed this maximum allowed luminance value. In one embodiment, the canvas window **210** can be placed into a luminance test mode. When in the luminance test mode, the color correction system tests the all the pixels in an image to determine if the luminance of each pixel is close to or above an acceptable luminance
10 threshold value. An example of luminance test mode will be described with reference to **Figures 3(a) to 3(c)**.

Figures 3(a) illustrates a canvas window video frame **310** that is tracking a ski jumper that will soon pass by the sun **320** that is currently not in the video frame.
15 The sun emits so much light that it can easily cause image pixels having luminance values that are out of range. Referring to **Figure 3(a)**, since the skier is not yet close enough to the sun, all the pixels are currently within the luminance limit. Thus, when all the pixels are within the maximum luminance value, the canvas window video frame **310** may simply display an indication such as the “OK” indication **350** that indicates that the image
20 is compliant with the luminance restrictions.

Referring to **Figure 3(b)**, as the skier comes closer to the sun, some of the pixels in a halo around the sun come very close to the maximum luminance value allowed for broadcast material. In one embodiment, “very close” is defined as within 10%
25 maximum luminance value allowed for broadcast material. To warn the user about this,

the luminance test mode displays a warning indication **360** in the canvas window video frame **310**. Furthermore, the luminance test mode highlights the pixels **331** very close to the maximum luminance value. In one embodiment, the pixels are “zebra striped” with green stripes. Note that the zebra striping allows the underlying image to remain visible.

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Finally, referring to **Figure 3(c)**, the skier is close to the sun such that some of the pixels from a halo around the sun come exceed the maximum luminance value allowed for broadcast material. To alert the user about the “illegal” pixels, the luminance test mode displays a violation indication **370** in the canvas window video frame **310**. Furthermore, the luminance test mode highlights the pixels **332** very close to the maximum luminance value and the noncompliant pixels **342** that exceed the maximum luminance value. In one embodiment, the pixels close to the maximum luminance value are zebra striped with green stripes and the pixels exceeding the maximum luminance value are zebra striped with red stripes.

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In alternate embodiments, the luminance test mode may display pixels “close” (within 20%) with green zebra striping, “very close” (within 10%) with yellow zebra striping, and exceeding the maximum luminance value with red zebra striping. Furthermore, in one embodiment the canvas window video frame implements a saturation test mode. When in the saturation test mode, the pixels that exceed the maximum allowed color stripes are highlighted with zebra striping. In a preferred embodiment, the user may activate the luminance test mode and the saturation test mode simultaneously such that the user can locate over saturated pixels and pixels that exceed the maximum allowed luminance value at the same time.

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Workbench Scopes Window

A second window **220** is a “workbench” window that displays a number of commonly used scopes for video editing. The workbench window **220** may include scopes such as a waveform monitor, a vectorscope, and a luminosity histogram as is well known in the art. Other useful graphs may be created or subsequently added at a later date. The combination of the canvas window **210** and the workbench window **220** provide feedback to the user.

Color Correction Tools Window

The third window **230** is a color correction interface window that contains tools for performing color correction. The color correction interface window **230** comprises a graphical user interface containing several different color correction tools for performing color correction on the images in the canvas window **210**. The graphical user interface containing several different color correction tools for performing color correction and the methods that implement those color correction tools are one of the primary focuses of this document.

A Color Correction Graphical User Interface

Figure 4 illustrates one embodiment of a graphical user interface for the color correction window **230** of the present invention. Other embodiments will be described but practicing the invention does not require implementing all the features of one particular embodiment.

Color Plane Adjustment Pads

In the color correction window **230** embodiment of **Figure 4**, there are three different color adjustment pads **430**, **420**, and **410**. Each color adjustment pad displays the spectrum of hues around the perimeter. The primary and secondary colors of the spectrum are labeled on the color adjustment pad spectrum as Red (R), Magenta (Mg), Blue (B), Cyan (Cy), Green (G), and Yellow (Yl). Different saturation levels are displayed for each hue with zero saturation (white) in the center. A hatch mark **431**, **421**, and **411** specifies the normal flesh tone hue for the different color adjustment pads **430**, **420**, and **410**, respectively.

The color adjustment pads **430**, **420**, and **410** allow the user to adjust the meaning of “white”, “gray”, and “black” respectively by shifting the center toward a particular hue. Specifically, a user may use a cursor control device to draw a vector from the center **431**, **421**, and **411** of a color adjustment pad toward a particular hue (angle) for a specified distance (magnitude). The color correction then adjusts all the colors accordingly. In a preferred embodiment, the controls produce relative adjustments.

The three different color adjustment pads **410**, **420**, and **430** correspond to constant luminance planes in the three-dimensional colorspace illustrated in **Figure 5**.

Specifically, whites color adjustment pad **430** corresponds to whites luminance plane **530**, mids (middle) color adjustment pad **420** corresponds to a mids (middle) luminance plane **520**, and blacks color adjustment pad **410** corresponds to blacks luminance plane **510**. The three different color adjustment pads **430**, **420**, and **410** allow a user to adjust the colors of pixels havening the luminance level of the corresponding luminance plane **530**, **520**, and **510**, respectively.

Each color adjustment pad **410**, **420**, and **430** includes an associated reset button **417**, **427**, and **437**, respectively. The reset button resets the color balance to the default (no adjustment) state.

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Each color adjustment pad **410**, **420**, and **430** also includes an eyedropper button **415**, **425**, and **435**, respectively. The eyedropper button allows the user to select a color from the image and define that selected color as the center (unsaturated) value of the associated luminance plane. In this manner, a user may perform post-production white balancing by selecting a colored pixel from an object known to be white in an image.

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When an adjustment is made for a particular luminance level, other luminance levels are affected as well. When the whites color adjustment pad **430** or the blacks color adjustment pad **410** is used to adjust the whites luminance plane **530** or blacks luminance plane **510**, respectively, all the other luminance planes are adjusted proportionally according to their distances from the adjusted luminance plane. In one embodiment, an adjustment to the whites luminance plane **530** or blacks luminance plane **510** causes the other luminance planes to be adjusted depending on how close those planes are to the adjusted luminance plane. When the mids color adjustment pad **420** is used to adjust the mids luminance plane **520**, then the other luminance planes are also adjusted. However, in one embodiment, an adjustment to the mids luminance plane **520** causes the other luminance planes to be adjusted according to a curve depending on how close those planes are to the adjusted mids luminance plane **520**.

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Color Plane Adjustment Examples

Referring to **Figure 4**, if the user moves the center of the whites color adjustment pad **430** to the right, the pixels of the high luminance level plane **530** are adjusted toward the blue (B) hue and lower luminance level planes are adjusted proportionally. Specifically, **Figure 6(a)** illustrates how the three-dimensional colorspace is adjusted when the user moves the center of the whites color adjustment pad **430** to the right by an amount of ΔX . Note that the mids luminance plane **620** is moved over half as much ($(\Delta X)/2$) as the whites luminance level plane **630** and that the blacks luminance level plane **610** is not adjusted at all. Note that the luminance axis Y now extends upward at an angle into the colorspace.

Similarly, if the user moves the center of the blacks color adjustment pad **410** to the right, the pixels of the blacks luminance level plane are adjusted toward the blue (B) hue and higher luminance level planes are adjusted proportionally. Specifically, **Figure 6(b)** illustrates how the three-dimensional colorspace is adjusted when the user moves the center of the blacks color adjustment pad **410** to the right by an amount ΔX . Again, the mids luminance plane **670** is moved over half as much ($(\Delta X)/2$) as the blacks luminance plane **660** and the whites luminance level plane **680** remains stationary.

If the user moves the mids (middle) color adjustment pad **420**, the system moves colors of the mids luminance plane **520** accordingly. The other luminance planes are also moved, but by an amount specified by a curve. Specifically, **Figure 7** illustrates how the three-dimensional colorspace is adjusted when the user moves the center of the mids color adjustment pad **420** to the right by an amount ΔX . As illustrated in **Figure 7**, the mids luminance plane **720** is moved over by the amount ΔX specified by the user.

The other luminance level planes are adjusted in the same direction by an amount specified by a combination of ΔX and curve 750. In one embodiment, curve 750 is defined as a well-known Bezier's curve. Note that the luminance axis Y is now curved.

5 The movements of the three different color adjustment pads 430, 420, and 410 may be combined to create different colorspace adjustments. For example, the user may first adjust the whites luminance level plane 530 to right by ΔX using the whites color adjustment pad 430 to produce the adjusted colorspace illustrated in **Figure 6a**. The user may then subsequently adjust the mids luminance plane 520 using the mids color adjustment pad 420. **Figure 8** illustrates how the three-dimensional colorspace is 10 appears after the user moves the center of the mids color adjustment pad 420 to the right by an amount of $\Delta X'$. Note that the mids luminance level plan 892 has been shifted by $\Delta X'$ but whites luminance level plane 893 and the blacks luminance level plane 891 remain stationary. However, all the other luminance planes are adjusted according to 15 curve 895. Additional details on one implementation of the math behind these color adjustments will be presented later in this document.

Luminance Adjustment Sliders

Referring back to **Figure 4**, the graphical user interface further includes 20 three luminance adjustment sliders 439, 429, and 419 associated with each of the three luminance planes illustrated in **Figure 5**. Specifically, **Figure 4** illustrates whites luminance slider 439, mids luminance slider 429, and blacks luminance slider 419. The luminance adjustment sliders 439, 429, and 419 adjust the luminance levels of pixels on luminance plane 530, 520, and 510, respectively.

As with the color adjustment pads, the luminance sliders adjust the luminance on their respective luminance planes. The whites luminance slider **439** adjusts the luminance for the pixels on the whites luminance plane **530** and the remaining luminance planes as a function of how close those other planes are to the whites

5 luminance plane as illustrated by the input (x)/output (y) graphs in **Figure 13**.

Specifically, moving the whites luminance adjustment slider **439** to the right increases the luminance of high luminance pixels as illustrated in **Figure 14(c)**. Similarly, moving the whites luminance adjustment slider **439** to the left lowers the luminance of high

10 adjustment slider **439** in the center leaves the high luminance pixels unchanged.

The blacks luminance slider **419** adjusts the luminance for the pixels on the blacks luminance plane **510** and the remaining luminance planes proportionally.

Specifically, adjusting the blacks luminance slider **419** to the left decreases the luminance
15 as illustrated by the input(x)/output(y) graphs of **Figure 14(a)** and adjusting the blacks luminance slider **419** to the right increases the luminance as illustrated in **Figure 14(b)**.

The mids luminance slider **429** adjusts the luminance of pixels on the mids luminance plane **520**. In one embodiment, the adjustment to the mids luminance slider
20 adjusts the other luminance planes in a curved manner according to a curve as illustrated in **Figures 14(e)** and **14(f)**. Specifically, moving the mids luminance slider **429** to the right raises the luminance of the mids as illustrated in **Figure 14(e)** and **14(g)** and moving the mids luminance slider **429** to the left lowers the luminance of the mids as illustrated in **Figure 14(g)**.

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Auto-Contrast Buttons

In the center of the graphical user interface of **Figure 4** is a set of auto-contrast buttons **460**. The auto-contrast buttons **460** are used to analyze a frame of the image being manipulated and then automatically adjust the luminance of the image.

- 5 Specifically, the auto-contrast buttons **460** automatically adjust the blacks luminance slider **419** and whites luminance slider **439** to values which will expand or contract the luma values in the original images to fall into the maximum CCIR-recommended luma ranges (16 and 235).

- 10 Referring to the auto-contrast buttons **460** in **Figure 4**, the specific auto-contrast buttons from left to right are: auto-black-level, auto-contrast, auto-white-level. The Auto-black-Level button will adjust the blacks slider to make the lowest input luma value map to CCIR-black (16). The Auto-White-Level button will adjust the highest input luma value to map to a user-specified white value. This user-specified white value
15 is normally CCIR-white (235). The auto-contrast button performs both operations (auto-black-level and auto-white-level) in one step.

- These auto-contrast buttons **460** are highly desirable since one of the tasks that professional colorists often perform is to adjust the black and white levels to see what
20 contrast the original image has. After seeing the contrast in the original image, the colorist may increase (or decrease) the image's contrast as appropriate.

Saturation Adjustment Slider

- Referring again to **Figure 4**, a saturation adjustment slider **450** can be used
25 to adjust the saturation of all the pixels. The saturation adjustment slider **450** adjusts the

saturation of the effected pixels by multiplying each pixel's current saturation value with a saturation multiplier value between zero and two.

Adjusting the saturation with a saturation multiplier value of zero would change all the pixels to zero saturation, resulting in a Black and white image. Adjusting the saturation with a saturation multiplier value of two would double the saturation of each pixel. Leaving the saturation adjustment slider **450** in the center position multiplies the saturation by a value of one and thus does not change the saturation of the pixels.

Limit Effect Panel

To limit the effects of color correction, the user may define a limited three-dimensional space within the three-dimensional colorspace that should be adjusted.

Referring to **Figure 4**, the "limit effect" panel **460** at the bottom of the graphical user interface allows the user to specify a limited volume within the colorspace by selecting a particular hue range, saturation range, and luminance (luma) range. Limiting the effected pixels is also known as "keying."

Referring back to the colorspace illustration of **Figure 1(b)**, an example of a defined three-dimensional space **150** within the three-dimensional colorspace is illustrated. Three-dimensional space **150** is defined with a Δy luminance range, a Δs saturation range, and a Δh hue angle range. Not all three parameters need to be specified. If a particular parameter is not specified, then the entire range of that parameter will be adjusted with the color corrections. If no parameter is specified, then all the pixels will be effected.

Referring back to the limit effect panel **460** of **Figure 4**, a user may specify a Δh hue angle range by marking the hue angle range checkbox **478** (which indicates that the Δh hue angle range should be considered) and defining a hue angle range on the hue spectrum **470**. The Δh hue angle range is specified along a hue spectrum **470** using a pair of defining hue markers **471** and **472**.

The angle determined by the defining hue markers **471** and **472** is used to allow the user to generate a smooth falloff for the color effect. For colors completely inside the defining hue markers **471** and **472**, the effect is applied 100%. For colors completely outside the defining hue markers **471** and **472**, the effect is not applied. For colors that fall into the “falloff area” which the user specifies by the angle of the defining hue markers **471** and **472**, the resulting pixel is calculated by blending the original, unmodified pixel with the pixel after the effect has been applied. The effect is proportional to where the original pixel color is in the falloff area. Thus, the angled defining hue markers **471** and **472** allows for a smooth gradation between pixels subject to the effect and pixels not subject to the effect.

The user may press hue angle reset button **477** to reset the defined hue angle to a default hue angle. In one embodiment, the default hue angle is -110° with a default width of 15° and a default softness of 10. The user may center the hue spectrum **470** on a particular hue by selecting a hue from the image using eyedropper button **474**.

A user may specify a Δs saturation range by marking the saturation range checkbox **488** and defining a saturation range on the saturation scale **480**. The Δs saturation range is specified along the saturation scale **480** using a pair of defining

saturation markers 481 and 482. As set forth with reference to the defining hue markers 471 and 472, the angle determined by the defining saturation markers 481 and 482 is used to allow the user to generate a smooth falloff for the color correction. The user may press saturation range reset button 487 to reset the defined saturation range to a default saturation range. In one embodiment, the default saturation range starts at 35% with a width of 40 and a softness of 20. The user may center the saturation markers 481 and 482 around a particular pixel's saturation value by selecting a pixel from the image using eyedropper button 474.

Finally, a user may specify a Δy luminance range by marking the luminance range checkbox 498 and defining a luminance range on the luminance scale 490. The Δy luminance range is specified along the luminance scale 490 using a pair of defining luminance markers 491 and 492. As set forth with reference to the defining hue markers 471 and 472, the angle determined by the defining luminance markers 491 and 492 is used to allow the user to generate a smooth falloff for the color correction. The user may press luminance range reset button 497 to reset the defined luminance range to a default luminance range. In one embodiment, the default luminance range starts at 0% with a width of 40 and a softness of 20. The user may center the luminance markers 491 and 492 around a particular pixel's luminance value by selecting a pixel from the image using eyedropper button 474. Furthermore, if the user activates the eyedropper while holding the shift key down then the hue, saturation, or luminance on which the user clicks will be added to the keying selection.

Alternative Color Correction Graphical User Interfaces

The graphical user interface for the color correction window may be implemented in many different manners. The different color correction graphical user interface embodiments may include new features and omit other features.

Figure 9 illustrates a first alternate embodiment of a color correction user interface. In the embodiment of **Figure 9**, there is only a single color adjustment pad **910** for adjusting the whites luminance plane **530** as illustrated in **Figure 5**. Thus, in the embodiment of **Figure 9**, only the whites luminance plane **630** may be adjusted as illustrated in **Figure 6(a)**. However, the embodiment of **Figure 9** includes all three luminance adjustment sliders **939**, **929**, and **919** such that the luminance levels of all three different luminance planes **530**, **520**, and **510** may be adjusted accordingly.

Hue Phase Shift Adjustment

The color correction embodiment of **Figure 9** introduces a new color adjustment device, the hue adjustment wheel **920**. The hue adjustment wheel **920** allows the user to simultaneously adjust the hues of all the pixels (defined by the limit effect panel) by rotating the colorspace. Specifically, a user may rotate the outer wheel **921** to rotate the hue spectrum. This causes the entire colorspace to be rotated by a corresponding amount as illustrated by the arrow **521** in **Figure 5**. This type of color change is sometimes known as a hue phase shift. To reset any hue phase shift changes, the user may activate the hue rotation reset button **527** to move the hues back to their original (default) position.

Figure 10 illustrates a second alternate embodiment of a color correction user interface. In the embodiment of **Figure 10**, there are three color adjustment pads **1010**, **1020**, and **1030** as well as a hue adjustment wheel for adjusting the hues in a colorspace. The color correction user interface of **Figure 10** is very powerful since it contains all the features of the previous two user interfaces, but the color correction user interface of **Figure 10** is slightly cluttered.

Color Correction Implementation

The present invention provides for color correction in a novel manner by performing the color correction and keying in the YUV colorspace in order to reduce processing cycles and to save time through the avoidance of rendering. This is in marked contrast to prior art techniques that perform color correction in the RGB space and, thus, tend to involve greater amounts of rendering. By reducing or removing the time consuming rendering steps, the system of present invention is more efficient than prior art systems.

As will be described more fully in the sections hereafter, the inventive techniques utilize look-up tables (LUTs) that may convert user inputted color corrections to the YUV or YCrCb colorspace in selected images to an outputted value. Although YUV and YCrCb denote different values mathematically, for purposes of the present invention, YUV and YCrCb are deemed interchangeable as used herein. The look-up tables (LUTs) that provide for the remapping of pixels according to the user's desired color correction are used to provide a high performance pixel remapping. However, the

color correction pixel remapping performed by the present invention may be implemented in other manners.

To fully describe the implementation of all the different features, the implementation will be described with reference to the color correction graphical user interface of **Figure 10**. The color correction graphical user interface of **Figure 10** includes user interface devices for adjustment of color space shifting, hue phase shift, luminance levels, and saturation.

Figure 11 illustrates a flow diagram containing, a segment of the inventive technique in one embodiment. User input representing the desired color correction is received at **1110** for a given color space. The user input may be provided using of the graphical user interfaces depicted in **Figures 4, 9, or 10**. In one embodiment, the user input from the color adjustment pads may be in the form of a vector that is converted at **1120** to Cartesian coordinates for computational purposes. In another embodiment, however, it is possible to have the user input directly in the form of Cartesian coordinates, without the use of vectors.

Once Cartesian coordinates form, a recomputation of the applicable look-up tables (LUTs) is performed at **1130**, the details of which will be discussed in greater detail below. Note that in certain applications, however, it may not be necessary to recompute one or more LUTs, given that it is possible that a user may only modify a parameter that does not require a look-up table recomputation such as a saturation adjustment. Finally, the color information of designated pixels are remapped at step

1140. In one embodiment, the YCrCb values that define the designated pixels are remapped with the aid of the recomputed from the look-up tables (LUTs).

Figure 12 illustrates a flow diagram describing the pixel remapping

5 referred to in step 1140 of **Figure 11**. The pixel color correction may begin by receiving a pixel at step 1210.

Based on user input from the previously described luminance adjustment sliders, an adjustment to the pixel's luminance is made at step 1220 based on the
10 luminance look-up tables (LUTs), as described in greater detail hereafter. Specifically, the luminance (Y) of a pixel is set with the following equation:

$$Y = yLUT(Y) \text{ where } Y \text{ is the pixel's luminance value}$$

As such, the previously described luminance adjustment sliders are able to provide user control of the luminance (Y) value of a YCrCb defined pixel.
15

Next, an adjustment to the chrominance is made at 1230 based on the chrominance look-up tables (LUTs) that have been modified based on user input from the color adjustment pads as previously disclosed. Note that the chrominance adjustment is relative to the initial chrominance value. The chrominance values are adjusted with the
20 following equations:

$$Cb = Cb + \text{signedCbLUT}(Y); \text{ and}$$

$$Cr = Cr + \text{signedCrLUT}(Y) \text{ where } Y \text{ is the pixel's luminance value}$$

As such, the previously described color adjustment pads are able to provide user control of the chrominance (Cr and Cb) values of a YCrCb defined pixel.
25

Also as previously described, the color correction user interface may include a hue adjustment wheel that may rotate the hues of pixels. The hue rotation may

be expressed as a phase shift h . In accordance with one embodiment, a final assignment of chrominance is made, based on any existing phase shift h , at step **1240**. The phase shifted chrominance values are determined from the previous chrominance values and the phase shift h . The general equations for this determination are:

5
$$\begin{aligned} C_b &= C_b * \cos(h) - C_b * \sin(h); \text{ and} \\ C_r &= C_r * \cos(h) - C_r * \sin(h). \end{aligned}$$

In systems without a hue adjustment wheel for phase modification h , there would be no need for step **1240** of **Figure 12**.

10 A final adjustment is made to a pixel's C_r and C_b values at step **1250**, based on a saturation adjustment s . The saturation adjustment s (or satadjust) may increase or decrease the amount of color depending on user input using the saturation adjustment slider. This increase or decrease is accomplished by setting the saturation adjustment s to a value between 0 and 2 inclusive and then multiplying the above final
15 color correction results by the factor of s to get the final adjusted color correction. Specifically, the following equation may be used to implement saturation adjustments to the pixels:

$$\begin{aligned} C_b &= 128 + (\text{satadjust} * (C_b - 128)); \text{ and} \\ C_r &= 128 + (\text{satadjust} * (C_r - 128)) \end{aligned}$$

20 Although it is possible to use other s values beyond the range of 0 and 2, such values tend to have little utility, given that the extremes of 0 to 2 represent the mainstream uses of color, where 0 represents no saturation, and 2 represents double the normal saturation for any given color.

25 Steps **1210** through **1250** are then repeated until the last pixel from the designated image(s) has been remapped, as determined at **1260**.

Luminance Correction: LUT Recomputations

As set forth in the flow diagram of **Figure 12**, the first pixel adjustment in one embodiment of the present invention is to adjust the pixel's luminance (Y) value.

- 5 The adjusted luminance value is based on the pixel's current luminance value and input from the user on the luminance sliders in the graphical user interface. The user input is used to adjust a luminance look up table that will be used to modify the luminance of each affected pixel.

10 **Figure 13** illustrates a graphical representation of the potential transitions for the relationship between the different pixel luminance input values on the input (x) axis **1305** versus the respective pixel luminance output values on the output (y) axis **1310**. As previously set forth, a user may adjust the luminance adjustment sliders in order to modify luminance control values W , M , and B .

15 The changes of in the luminance control values W , M , and B adjust the input/output graph as set forth in **Figure 13**. Specifically, changes to the W luminance control value may adjust the input/output graph in the directions indicated at **1320**, changes to the M luminance control value may adjust the input/output graph in the
20 directions indicated at **1330**, and changes to the B luminance control value may adjust the input/output graph in the directions indicated at **1340**.

Figures 14(a) to 14(g) illustrate more specific examples which are controlled for movement of individual variables in accordance with the previously
25 described user interface. Specifically: **Figure 14(a)** illustrates the resulting input/output

In one embodiment, the curve for the *M* control is calculated using Bezier control points k0 1410, k1 1460, k2 1480 and k3 1440. The endpoints k0 1410 and k3 1440 for the Bezier curve are calculated the same way as they would be for a linear case, as shown in **Figures 14(a) to 14(d)**, and are derived solely from the blacks luminance slider 419 and whites luminance slider 439 of **Figure 4**. MidPt 1430, Corner 1450, and CtlPt 1470 are all intermediate values used to illustrate how k1 1460 and k2 1480 are derived from k0 1410, k3 1440, and the previously described *M* adjustment slider, the middle Bezier control points (k1 1460, k2 1480) are calculated as follows.

First, a calculation is made for the midpoint between k0 1410 and k3 1440.

Specifically:

$$\text{MidPt.h} = \frac{(k0.h + k3.h)}{2}$$

A similar expression may be likewise employed for midPt.v. Next, a choice is made designating either the upper left or lower right, depending on the direction *M* is being pushed, such that:

If $M < 100$, lower right, then Corner.h = k3.h and Corner.v = k0.v
Else if $M > 100$, upper left, then Corner.h = k0.h and Corner.v = k3.v.

Next, a calculation is made as to how far out to go on the line between MidPt 1430 and

Corner 1450. Specifically, CtlPt 1470 is interpolated by using a weighting derived from $\text{weight} = \text{abs}((\text{mids}-100)/100.0)$ where the larger the *M* (“mids”) value, the more influence that Corner 1470 will have. Conversely, the smaller the value, the less influence Corner 1470 will have, e.g.:

$$\text{CtlPt.h} = \text{weight} * \text{Corner.h} + (1.0 - \text{weight}) * \text{MidPt.h}$$

A similar expression may be employed to obtain CtlPt.v.

Next, a calculation is made to determine k1 1460, by interpolating between k0 1410 and CtlPt 1470, again using the above-described weighting factor:

$$k1.h = \left(\frac{0.5 + (1.0 - weight)}{2}\right) * CtlPt.h + \left(\frac{1.0 - 0.5 + (1.0 - weight)}{2}\right) * k0.h$$

A similar expression may be employed to obtain k1.v.

5

Likewise, a calculation is made to determine k2 at 1480:

$$k1.h = \left(\frac{0.5 + (1.0 - weight)}{2}\right) * CtlPt.h + \left(\frac{1.0 - 0.5 + (1.0 - weight)}{2}\right) * k3.h$$

A similar expression may be employed to obtain k2.v.

10 **Figure 14(g)** illustrates where these points would lie relative to k0 1410 and k3 1440 for $M > 100$. As M (and therefore the above described “weight”) is changed, CtlPt will be interpolated to different locations along the line between Corner 1450 and MidPt 1430. Furthermore, k1 1460 and k2 1480 will be interpolated to different positions on the lines between k0 1410 and CtlPt 1470 and between k3 1440 and CtlPt 1470. The arrows at k1 1460, CtlPt 1470, and k2 1480 suggest how these points move as
15 the mids (M) luminance slider is adjusted (in the range 100-200).

Note that if $M < 100$, then the lower right corner of the bounding box formed by (k0, k3) would be used as Corner, and the curve would then inflect in the other direction, but otherwise, the relative positioning of the points (based on “weight”) is the
20 same. If, however, M was set to 100, the graph would instead be a straight line as shown in **Figure 14(a)** to **14(d)**.

Chrominance (U and V) Correction: LUT Recomputations

25 As discussed with reference to **Figure 12**, the second adjustment in one embodiment of the present invention is a pixel chrominance adjustment based on input

from the user on the color adjustment pads. Adjustments to the color adjustment pads skew the three-dimensional color space such that the chrominance value for each pixel must be changed. For example, **Figure 6(b)** illustrates how the three-dimensional colorspace is adjusted when the user moves the center of the blacks color adjustment pad

410 to the right by an amount ΔX . In mathematical terms, the effect of an adjustment of ΔX to the whites (W) luminance plane or blacks (B) luminance plane on the mids (M) luminance plane would be that of $\frac{\Delta x}{2}$ for a movement of Δx by W or B , as depicted in

Figures 6(a) and 6(b). An adjustment to the mids (M) luminance plane would affect the cylindrical representation along the Bezier shaped luminance axis (Y) as broadly depicted in **Figure 7**, and as will be more fully detailed in the below exemplary applications.

When a user makes adjustments to a color adjustment pad, the user's input may be received as an angle and magnitude defined vector. The angle and magnitude defined vector is then translated into a relative U,V vector for that luminance plane. For example, referring to **Figure 5**, a vector input for the white color adjustment pad would be translated into a Cartesian vector with a U_W value specifying a relative move along the U-axis and a V_W value specifying a relative move along the V-axis. Thus, for the example of **Figure 6(a)**, the relative Cartesian vector would be $U_W = \Delta X$ and $V_W = 0$.

To convert an angle vector push defined by magnitude m and an angle α , the Cartesian vector U and V can be found according to the generalized equations:

$$\begin{aligned} U_W &= m_W * \sin \alpha_W & V_W &= m_W * \cos \alpha_W \\ U_M &= m_M * \sin \alpha_M & V_M &= m_M * \cos \alpha_M \\ U_B &= m_B * \sin \alpha_B & V_B &= m_B * \cos \alpha_B \end{aligned}$$

Figure 15 illustrates an unchanged cylindrical colorspace representation where the white (W), mid (M), and black (B) luminance planes are physically centered on the $C_b = 0, C_r = 0$ axis. Thus, in **Figure 15**, all of the relative Cartesian vector values $U_W, V_W, U_M, V_M, U_B, V_B$ are zero. In **Figure 15**, the C_b look-up table (CbLUT) and the

5 C_r look-up table (CrLUT) are both of the form $y = 0$, a constant of zero. Applying the functions CbLUT and CrLUT, for any luminance value, the result is always $CbLUT[luminance] = 0.0$ and $CrLUT[luminance] = 0.0$.

Figure 16 illustrates another example of the cylindrical colorspace

10 representation where the white (W), mid (M), and black (B) luminance planes have all been shifted such that each has been pushed an equal amount to reflect different amounts of C_b and C_r values. As in the previous diagram, the vertical line in **Figure 16** is centered on the $C_b = 0, C_r = 0$ location for all three luminance planes. In **Figure 16**, C_b has been pushed by -0.30 and C_r has been pushed by 0.10 . Thus, CbLUT and CrLUT

15 are both of the form $y = C$ (e.g., a constant) given that the same amount of push is applied to C_b and C_r regardless of luminance. Specifically, for all luminance values, $CbLUT[luminance] = -0.30$ and $CrLUT[luminance] = 0.10$.

Figure 17 illustrates a more complex example of adjusting the cylindrical

20 colorspace representation where the white, mid, and black luminance planes are being pushed differently. To interpolate the adjustments for the luminance planes in between the white, mid, and black luminance planes, a Bezier curve is used. Although this implementation uses a Bezier function to generate a curve that users have found to be appropriate for the given color correction, other functions that generate similar curves and

25 even other curves may also be used.

Figure 18 illustrates a graph **1894** created from two Bezier curves connected by a linear segment (between **1890** and **1880**), with theoretical control points (**1810**, **1820**, **1890**, and **1892**) and (**1880**, **1870**, **1840**, and **1850**). Utilizing the graph

5 **1894** created from two Bezier curves connected by the linear segment, a more specific instantiation may be arrived at such as in **Figure 19**, where the graph created from two Bezier curves and the linear segment is termed “gMidRamp”. The gMidRamp, as detailed in the below mathematic equations, is used to generate look up table for Cb, (CbLUT) as illustrated in **Figure 20** and a look-up table for Cr (not shown).

10 Referring back to **Figure 18**, the Bezier control points for gMidRamp may accordingly be derived where the detailed control points assume that luma = 0 corresponds to CCIR-black and luma = 219 corresponds to CCIR-white (and values above 219 are superwhite). Additional assumptions in this illustrative case are such that:

15 (1) the lookup table size is assumed to be 256; (2) the lookup table is pre-initialized below 55 with 0 and above 164 with 0; (3) the lookup table is pre-initialized between 55 and 164 with 1.0; (4) the Bezier curves are placed with a left endpoint (0,0) at array index 4 (**1810**) and right endpoint (1.0, 1.0) at array index 104 (**1890**), and control points of (0.25, 0.0) (**1820**) and (0.75, 1.0) (**1892**), as shown at left side of **Figure 18**; and (5) the

20 curves are further placed with a left endpoint (0.0, 1.0) at array index 114 and a right endpoint (1.0, 0.0) at array index 214 (**1850**), and control points of (0.25, 1.0) (**1880**) and (0.75, 0.0) (**1840**), as at right. Hence, from left to right, the circles are control pts k0, k1, k2, k3, and k0, k1, k2, k3. The graph starts at 0, and tick marks represent 50% luma (114.5) and CCIR-white (219) (**1860**).

Referring back to **Figure 17**, the relative Cartesian vectors (U_W, V_W) and (U_B, V_B) are generated directly from the user's inputs to the white and black color adjustment pads. However, the Cartesian vector for the mids (M) luminance plane is a combination of the user input for the blacks and whites luminance planes along with the user's direct input for the mids luminance plane. Specifically, the Cartesian vector for the mids luminance plane (U'_M, V'_M) is generated with:

$$U'_M = \frac{U_W + U_B}{2} + U_M$$

$$V'_M = \frac{V_W + V_B}{2} + V_M$$

where U_M and V_M represent the user's directly specified offset for the mids luminance plane.

Accordingly, to generate the needed Cb look-up table (CbLUT) of **Figure 20**, the following equations are used:

for $i < 50\%$ White (CCIR luminance value of 128) then

$$\text{CbLUT}[i] = U_B * (1.0 - g\text{MidRamp}[i]) + U'_M * (g\text{MidRamp}[i])$$

for $i \geq 50\%$ White (CCIR luminance value of 128) then

$$\text{CbLUT}[i] = U_W * (1.0 - g\text{MidRamp}[i]) + U'_M * (g\text{MidRamp}[i])$$

Thus, **Figure 20** illustrates the CbLUT function in this example where Cb is pushed a small negative amount on the mids luminance plane (M) (say, approximately -0.3) but has not been pushed at all on the blacks or whites luminance planes. In this example, Cr is not being pushed at all (No plane has been moved in the V direction) such that $\text{CrLUT}[i] = 0$ for all values of i .

Figure 21 illustrates another example of a modified cylindrical colorspace representation. In the modified the cylindrical colorspace representation of **Figure 21**, both the mids and the white luminance planes have been pushed. In this case, the same

techniques are used to create the chrominance look-up tables (CbLUT and CrLUT). Note the same gMidRamp function is used.

In the modified cylindrical colorspace representation of **Figure 21**, both Cb and Cr are being pushed at the mids (M) luminance plane and only Cb is being pushed at whites (W) luminance plane. Thus, the effect of mids and whites luminance plane adjustments on Cb (from the mids and whites color adjustment pads) can be seen in graph of the Cb look-up table (CbLUT) in **Figure 22** at the mid luminance levels and at the high (white) luminance levels. Referring to **Figure 23**, since Cr has only been pushed at the mids luminance plane, the Cr look-up table (CrLUT) is symmetric about the mid luminance level.

Keying To Limit Effects

In one embodiment, keying may be employed to limit the effect of color correction. **Figure 24** illustrates a broad description of the inventive color correction system according to the recomputation of YUV values by usage of look up tables as described for a keyed area. As indicated at **2405**, the first step and differentiating step from the process outlined in **Figure 11** involves identifying a keyed color region.

Generally speaking, the techniques of keying may be used to identify or designate an entire image or images, as well as specific portions thereof, or even may be applied to specific object or backgrounds, as known in the art of keying. Additionally, the key may be partial (semi transparent) in which case the color corrected result is mixed with the uncorrected (original) pixel, allowing for a smooth transition between corrected and uncorrected areas of the images when using the Limit Effect panel. In one embodiment, keying is performed using the limit effect panel **460** of **Figure 4**.

Figure 25 illustrates an overall description of the pixel remapping of the inventive color correction described in **Figure 12** but only over the keyed pixels. As indicated, the differentiating step for keying over a designated area occur at **2515**, where an assessment is made as to whether a pixel having color value YCrCb is in a keyed area.

5

The foregoing has described a method and user interface for performing color correction. It is contemplated that changes and modifications may be made by one of ordinary skill in the art, to the materials and arrangements of elements of the present invention without departing from the scope of the invention.

10